Simplified methods to evaluate energy use for space cooling in the energy certification

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SUMMARY

Both on European and national scale, standards are now being drawn to extend to summer air conditioning the evaluation of energy requirement in building-plant systems. To this aim different simplified methods have been taken into account, anyway all similar to the utilization factor method already used for the winter season.

The results obtained by the application of these methods in the case of typical buildings are therefore compared here with those from a dynamic simulation of building-plant system by means of comprehensive computer programs like Energy-Plus. The analysis points out the possibilities but also the limits of these simplified methods.

INTRODUCTION

Comprehensive software programs to simulate building energy performances in dynamic conditions are available today for professional purpose. But the use of simplified methods is still diffuse and recommended or sometimes even compulsory in various national standard. Also in the new European standard [1], in draft, for the calculation of energy use for space heating and cooling are foreseen both quasi-steady state methods and dynamic methods. At national level it may be decided which of these methods is or are allowed to be used.

Eventually depending on the purpose of the calculation and the complexity of building. With regard summer air conditioning, the actual tendency is to elaborate a simplified approach similar to the one used for heating requirements calculation and based on the utilization factor method. For example this method is already present in the standard EN 832 [2]. Naturally the application of this technique to the more complicated summer case is destined to increase the problems, the doubts and the criticisms which have appeared over the winter calculation. The possible application of the utilization factor method for the cooling calculation is therefore discussed here on the basis of the comparison with the results obtainable with the EnergyPlus program [3]. This is a dynamic simulation program of the building-plant system based on the most popular features and capabilities of BLAST [4] and DOE-2 [5] programs. Its development is supported by the US Department of Energy and actually it can be considered one of the most reliable software codes for building energy simulation.

THE APPLICATION CASES

For our investigations about summer requirement evaluations some typical application cases have been analysed. As the fundamental aim is to investigate the influence of the heat gains on the simplified calculation of the cooling needs, we have concentrated our attention about
office buildings normally characterized by greater heat fluxes than dwellings. Three buildings with different shapes have been considered: a single unit, an horizontal serie of units and a vertical serie. The three buildings are sketched in figure 1. One of the largest façades is always South oriented. The conditioned volume is respectively 432, 10368, 9720 m³ for the three buildings. Typical envelope structures have been assumed, for example brick walls well insulated as required by the current Italian laws. Double glazing 6+13+6 mm uncoated, clear and air filled with a thermal transmittance of 2.71W/m²K and a SHGC=0.70. Further details can be found in [6]. Three different amounts of external glazing have been considered: 10%, 50% and 100% of the external surfaces for the single unit, 20%, 50% and 100% for the horizontal and vertical volume. The air conditioning can be continuous or intermittent, from 7 am to 7 pm. (12h).

![Figure 1 A view of the analysed buildings](image)

Forced ventilation equal to 2 vol h⁻¹ is present only in the period from 7 am to 7 pm. Internal heat gains for persons (maximum 1 person 10 m⁻²), lighting (maximum 20 W/m², fluorescent) and different maximum electric machine gains (computers): 12, 48 W/m². Typical daily

![Figure 2 Percentage reduction of the cooling needs with intermittent instead of continuous air conditioning for the single unit in Venice with various electric gains and glazed quota.](image)
scheduling for office buildings are foreseen. The indoor air design temperature is 26°C, a standard value in Italy. The air conditioning period analysed is from May to September (5 months). The procedure to calculate energy requirement for humidity control will not be discussed here even if latent loads normally have an important effect on overall plant performance. In fact hygrometric load calculation is normally easier to do by a mass balance on the indoor air. The following considerations will refer only to sensible load estimation whose determination is undoubtedly more critical. For the simulation the weather of two different localities in Italy: Venice and Palermo have been utilized. They are assumed representative of the climate in the central and southern part of Europe.

In figure 2 the percentage reductions of the seasonal cooling needs with the intermittent instead of continuous air conditioning are presented in the case of single building with different internal electric gains and external glazed surface ratios. Unlike the winter case, the passage from continuous to intermittent plant operation does not cause noticeable differences in the seasonal requirement because the heat gains are normally concentrated on daytime. In this first phase of the analysis therefore, we have concentrated the attention on the plant continuous working case. All the results presented are referred to the continuous cooling.

THE UTILIZATION FACTOR METHOD

The monthly heating requirement for each zone \( Q_h \) of a building is calculated using the following correlation:

\[
Q_h = Q_l - \eta_u \cdot (Q_{si} + Q_i)
\]

where:
- \( Q_l \) is the total heat loss, sum of transmission and ventilation losses (J)
- \( Q_{si} \) is the solar gain through fenestrations (J)
- \( Q_i \) is the internal gain (J)
- \( \eta_u \) is the utilization factor of the heat gains

The utilization factor \( \eta_u \) is a reduction factor for the heat gain introduced to take into account of the dynamic behaviour of the building. The parameters having the greatest influence on the utilization factor are:
- the gain/loss ratio \( \gamma \) which is defined as:

\[
\gamma = \frac{Q_{si} + Q_i}{Q_l}
\]

- the time constant \( \tau \) which characterizes the internal thermal inertia of the heated space:

\[
\tau = \frac{C}{H}
\]

where \( C \) is the effective internal thermal capacity (J/K).

The utilization factor \( \eta_u \) is then calculated with the following equations:

\[
\eta_u = \frac{1 - \gamma^\alpha}{1 - \gamma^{\alpha+1}} \quad \text{if } \gamma \neq 1
\]
\[ \eta_u = \frac{\alpha}{\alpha + 1} \quad \text{if } \gamma = 1 \]  

(5)

where \( \alpha \) is a numerical parameter depending on the time constant \( \tau \).

\[ \alpha = \alpha_0 + \frac{\tau}{\tau_0} \]  

(6)

The values of \( \alpha_0 \) and \( \tau_0 \) are provided by the standard.

**THE APPLICATION TO AIR CONDITIONING**

In analogy with winter calculation the review of the standard EN 13790 proposes the evaluation of the cooling requirement \( Q_c \). In the summer period the heat gains become the fundamental cause of the air conditioning needs, instead the quantity \( Q_l \) due to transmission and ventilation normally reduces the cooling load. In fact, in the European climate the average monthly temperature of the outdoor air is lower than the indoor design temperature which is for example in Italy equal to 26°C. Therefore for each zone and in the case of continuous air conditioning, at the present time the standard suggests the following equation:

\[ Q_c = (Q_{si} + Q_i) - \eta_u \cdot Q_l \]  

(7)

where \( \eta_u \) becomes an utilization factor for heat losses and it is calculated again as a function of \( \gamma \) and \( \tau \) with different values \( \alpha_0 \) and \( \tau_0 \).

![Figure 3 Utilization factors with method A for the single unit in the various cases](image-url)

If these losses are negative (\( \gamma < 0 \)) the utilization factor will have the value one and consequently the negative losses are totally added as gains. By this procedure \( \eta_u \) can be less or equal one. An investigation on this procedure, here called method A, is carried on, starting, on monthly basis, from the cooling demand \( Q_c \), heat losses \( Q_l \) and heat gains \( (Q_i + Q_{si}) \) obtained by dynamic simulation with EnergyPlus program. In this way it is possible to calculate the corresponding utilization factor necessary with method A in order to obtain the
same $Q_c$. In the figures 3, 4, 5 this utilization factor is reported for the three considered buildings respectively and for the different localities, internal gains and glazed quota.

![Figure 4 Utilization factors with method A for the horizontal volume in the various cases.](image)

![Figure 5 Utilization factors with method A for the vertical volume in the various cases.](image)

An extreme variability of the utilization factor can be noted and this fact involves the difficulty to introduce a simple correlation able to calculate a correct value for the equation (7). Besides it is often strongly greater than the unit. This is because normally only a fraction of the heat gains contributes to the cooling requirements while a considerable quota is lost to the surroundings. Indeed this conclusion is not a great novelty for people familiar with cooling load calculations by dynamic simulation. The transfer function method from ASHRAE [6] foresees reduction coefficients for the various types of heat gains. The necessity to reduce also the heat gains is the reason of the utilization factors greater than one. In the same way when sometimes the heat losses are negative (i.e. in Palermo) the procedure can need negative values of $\eta_u$. We can conclude that especially in presence of remarkable solar contributions and smaller effect of free cooling connected with heat losses there is the necessity to introduce an utilization factor for the heat gain. Another method (here called method B) is then proposed and based on the following equation:

$$Q_c = \eta_u \cdot (Q_s + Q_v) - Q_l$$  \hspace{1cm} (8)
where $\eta_u$ becomes again an utilization factor for heat gains. For sake of simplicity an utilization factor of the heat losses is here neglected. The effort is to maintain a simple correlation like in the winter procedure. A verification of the method B is presented in the figures 6, 7 and 8 in the various cases. We can appreciate in this case the moderate variability of the values. In this way it is justified to consider eventual approximations or errors anyway of limited amount. The use of only one utilization factor for the heat gains seems to be able to

Figure 6 Utilization factors with method B for the single unit in the various cases.

Figure 7 Utilization factors with method B for the horizontal volume in the various cases.

Figure 8 Utilization factors with method B for the vertical volume in the various cases.
control in a correct way the effect of both the heat fluxes and contributions. In addition the figures show a greater influence of the percentage glazed quota than the internal gains on the values of utilization factors. It means that the solar contributions deeply influence the $\eta_u$. In particular we find, as foreseen, a significant reduction of the utilization factor by increasing the glazed quota i.e. the solar flux. On the contrary it is quite logical that an internal electric gain (computer, electric machines) becomes immediately a convective cooling load and then it is completely added to the cooling needs. The variability of $\eta_u$ regards therefore especially the solar gain. For this reason a third method (here called method C) is here analysed where the utilization factor is referred only to the solar contribution like presented in the following formula:

$$Q_c = \eta_u \cdot Q_{si} + Q_i - Q_l$$

(9)

A verification of the method C is presented in the figures 9, 10 and 11 in the various cases.

Figure 9 Utilization factors with method C for the single unit in the various cases.

Figure 10 Utilization factors with method C for the horizontal volume in the various cases.

The application of the method C points out a better sensibility of $\eta_u$ to the influence of the amount of glazed quota and therefore to the parameter $\gamma$. This fact confirms the correct interpretation of a reduction of the utilization of the heat gain only referred to the solar contribution which is absorbed first by the internal surfaces and later partially transferred to the internal air as a cooling load. This mechanism is influenced by the thermal inertia of the structures and the heat loss coefficient of the room. Besides, for the same glazed quota, the
figures show that the utilization factor increases lightly in presence of less internal gains. Also with method C therefore, it is correct the research of a correlation to calculate $\eta_u$ where the ratio $\gamma$ still contains all the heat gains.

DISCUSSION

The analysis confirms the possibility of a simplified estimation of building cooling requirement based on the utilization factor method likewise the procedure to calculate heating energy use. But in the cooling case the utilization factor must be referred to the free heat gains which are the fundamental heat fluxes which determine the air conditioning need. Instead in summer heat losses permit often a free cooling, but they are normally modest. Therefore a reduction coefficient of their influence on the cooling load is not the best way to take into account also the more significant reduction of the heat gains. The results of the dynamic simulation suggest the introduction of an utilization efficiency referred only to the solar contribution. It seems to be possible to evaluate it by an algorithm equal to that one already used for heating calculation as a function of the parameters $\gamma$ and $\tau$. But new correlations to calculate them will have to be elaborated and verified by an extended data base of simulation results with different building characteristics, use and climatic conditions.

REFERENCES

4. BLAST 1993. The building loads analysis and system thermodynamics program. Department of Mechanical and Industrial Engineering, University of Illinois at Urbana Champaign.